Art. XVIII.—*The Heathcotian—a Pre-Ordovician Series —and its Distribution in Victoria.*

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[Read 13th November, 1902].

[With Plates XXIII.–XXVI.].

I.—Introduction.

One of the most interesting and instructive rock series in Victoria occurs along the floor of the Heathcote Valley, and forms the crest of the Colbinabbin Range. Conflicting opinions have been expressed as to the age and character of these rocks. Several visits to different parts of the outcrop of the rocks suggested to me a solution, which promised, to some extent, to reconcile the views as to their interpretation. I have recently been able to test this idea during a four days' visit to Heathcote with my assistants, Messrs. H. J. Grayson and D. J. Mahony,

and the students of the Geological Department of the Melbourne University. Our joint examination of the country showed that the explanation was well founded.

Heathcote is a straggling township extended for about three miles along the Bendigo Road, in the broad valley of McIvor Creek. It is situated seventy-four miles northward from Melbourne. Along the floor of the Heathcote Valley, and upon its south-western slope are numerous exposures of a series of igneous rocks, which can be divided into an acid and a basic series. In close contact with these igneous rocks are some narrow belts of rocks which are clearly metamorphic sediments. These metamorphic and igneous rocks extend from the head of McIvor Creek, along a bold curve to the north-west; bending to the north, they are continued on the floor of the valley to the west of Mount Ida, whence they gradually rise and form the long Colbinabbin Range. The rocks of these metamorphic and diabase series extend along this line, with occasional slight interruption, for about thirty miles. On the north-eastern side of this line the rocks are quartzites of silurian age. On the outer side of the curve to the west and south-west the rocks are slates, quartzites, and sandstones of ordovician age.

II.—Previous Literature.

The literature begins in 1866 with Selwyn's Geological Sketch of the Colony of Victoria,[1] in which the rocks of this line are marked simply as trap, and they are described (p. 172) as dykes. More precise information was given by Selwyn in 1868 in his "Descriptive Catalogue of the Rock Specimens and Minerals in the National Museum, Melbourne" (p. 16), in which the rocks from Mount Camel, the highest peak in the Colbinabbin Range, were determined as diabase; but in the same work, in the list of errata, the name was changed to diorite, owing to the identification of the ferromagnesian constituent as an amphibole instead of a pyroxene. A material described as a mineral under the name of selwynite,[2] which occurs in these rocks four miles north of Heathcote was described as in "a vein in the upper

[1] A. R. C. Selwyn: Official Record Intercol. Exhib., Austral., 1866-1867, pp. 147-227.
[2] *Ibid.*, p. 18.

silurian rocks"; so that we must interpret Selwyn's view as being that the diabase series was intrusive in post-silurian times.

The next contribution to the Lower Palaeozoic geology of Heathcote was a short but important note by Mr. E. J. Dunn, published in 1889; he described the rock series as beginning with some "schistose beds," (p. 77), followed by lower silurian [ordovician] and upper silurian. That Dunn regarded the schistose beds as older than the ordovician is stated by Sir F. McCoy, when describing some markings from Heathcote which he determined as worm tracks. Dunn's "Notes" moreover state that the basic rocks, which he calls "greenstone" are intrusive.[1]

In 1894 Mr. Lidgey published a fuller account of the Heathcote rocks, in which he stated Mr. Dunn's views as to the pre-silurian [*i.e.*, ordovician] age of the metamorphic rocks. He added the opinion that the basic rocks were lavas and amygdaloids.

During the survey of this area by the Victorian Geological Survey, Mr. W. H. Ferguson discovered a series of fossils, which were described by Mr. R. Etheridge, jun., as of cambrian age. In 1896 Mr A. W. Howitt published the results of a most careful microscopic study of the rock specimens collected near Heathcote by the officers of the Geological Survey; he recognised the intrusive character of many of the rocks. According to his instructions, Mr. Lidgey re-examined the ground, and some of the sections were visited by Mr. Howitt. The result was the conclusion that the rocks of the diabase series were intruded in devonian times, and that they were injected along the line of junction of the ordovician and silurian series.

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1 McCoy's note suggested that Dunn had done more work on the Heathcote rocks than is given in his report of 1889. On enquiry in the Mines Department, I have seen a letter from Mr. Dunn (6th July, 1891) in which he clearly expresses the view that the Heathcote rocks include a pre-silurian system. He says—"The formation is of pre-silurian age, and the beds of which it consists comprise highly siliceous and jaspideous rocks, very talcose splintery schists, tufaceous deposits, quartzite, and ancient vesicular basalts, once surface flows but now intercalated with other strata. The railway cuttings near Heathcote expose a tongue of these rocks; they extend and widen out in a northerly direction towards Mounts Camel and Pleasant; how far they continue has yet to be determined, as I only discovered the formation on Saturday last, and traced it towards Mount Camel." Mr. Dunn then makes the interesting suggestion that these rocks have marked resemblences to the rocks of the Te Anari series in New Zealand.—J.W.G., 13-xi.-02.

Mr. O. A. L. Whitelaw, in the geological sketch map of the parish of Heathcote (1896), used the nomenclature based upon Mr. Howitt's view. Mr. W. H. Ferguson in 1900 described the relations of the beds yielding the fossils, described by Mr. Etheridge as cambrian. Mr. Hall has referred to the possibility of the occurrence of graptolites in these beds, in which he has "detected theca of the type of *Bryograptus.*" Ranft asserted the presence of ordovician graptolites at Costerfield.

The following bibliography enumerates the literature of the geology of Heathcote, excluding papers dealing only with the glacial deposits and mineralogy :—

1. Dunn, E. J.—Notes on the Geological Features of Heathcote and Neighbouring Parishes. Quart. Rep. Min. Dep., Dec. 31, 1888 (1889), pp. 76-77.
2. Etheridge, R., jun.—Evidence of the Existence of a Cambrian Fauna in Victoria. Proc. Roy. Soc. Vict., new ser., vol. viii., 1896, pp. 52-64, pl. 1.
3. Also Mon. Prog. Rep. Geol. Surv. Vict. No. 11, 1900, p. 26.
4. Ferguson, W. H.—Report on an Area of Cambrian Rocks at Heathcote. *Ibid.*, No. 2, 1899, pp. 23-25, 1 pl.
5. Hall, T. S.—Supposed Graptolites from Heathcote. *Ibid.*, No. 11, 1900, p. 26.
6. Howitt, A. W.—Notes on Diabase and Adjacent Formations of the Heathcote District. Spec. Rep. Dep. Mines Vict., 1896, 16 pp., 5 pl. [with appendix by E. Lidgey, p. 15].
7. Jenkins, H. C.—Report on the Heathcote, Costerfield, Graytown, Rushworth, Whroo, and Redcastle Districts. Spec. Rep. Dep. Mines Vict., 1900, 7 pp.
8. Lidgey, E.—Notes on Quarter Sheet No. 80, N.W.—Parishes of Dargile, Heathcote, Costerfield and Knowsley. Prog. Rep. Geol. Surv. Vict., No. viii., 1894, pp. 44-46, 4 pl. Also *vide* Howitt.
9. McCoy, F.—Report on Palaeontology of the Geological Survey for the Year 1891. Ann. Rep. Sec. Mines for 1891 (1892), p. 30.

10. Ranft, J. A. H. T.—Origin and Formation of Auriferous Rocks and Gold. Sydney, 1889.
11. Selwyn, A. R. C.—Notes on the Physical Geography, Geology, and Mineralogy of Victoria. Intercol. Exhib. Essays, 1866-67. Off. Rec., pp. 147-227.
12. Selwyn, A. R. C.—A Descriptive Catalogue of the Rock Specimens and Minerals in the National Museum. 96 pp. Melbourne, 1868.
13. Walker, B. D.—Report on Neglected Gold Fields, Part II., Spec. Rep. Dep. Mines Vict., 1894, 12 pp.
14. Whitelaw, O. A. L.—Geological Sketch Map of the Parish of Heathcote. Mines Dep., Sept., 1896.

III.—The Geological Sequence at Heathcote.

The palaeozoic rocks at Heathcote may be divided between four systems. The famous glacial deposits of Derrinal occur to the west; though often recorded as mesozoic, they are probably of upper carboniferous age. Their only concern with this paper is that they are rich in fragments of the metamorphic and diabase rocks. The remaining palaeozoic rocks belong to the silurian and ordovician systems, and to a group of igneous and metamorphic rocks.

III. (A).—*Silurian.*

The silurian rocks lie to the north-east of Heathcote, and occur as a thick series of breccias, conglomerates, quartzites and quartzose grits. Certain bands are extremely rich in fossil casts, including encrinite stems, brachiopods, gastropods, and occasional trilobites. I have not given attention to the palaeontology of these beds; but they contain a Homolonotus of the type found in the lower part of the Victorian silurian system. Further east the sandy type is less persistent and some shales occur. The prevalent strike of the silurian rocks is from north to south, but around Mount Ida the strike is from east to west; this change is no doubt due to a fault, which is now hidden by the valley to the south of the mountain. In the breccias the pebbles are mainly quartzites, derived in the main from the silurian and ordovician rocks. Mr. Lidgey has recorded the

occurrence of pebbles of the metamorphic rocks in the breccias on the summit of Mount Ida. (No. 8[1]).

The silurian rocks can be seen in close contact with the diabases on the eastern side of the Murray-road, opposite the so-called copper mine. There is no sign of any contact alteration of the silurian rocks there. The silurian sandstones are often reddish-brown, owing to the abundance of material, which the microscope shows to be mainly decomposed diabase.

The junction of the silurian rocks with the diabase series is rarely shown, as they are generally separated by the alluvium along the McIvor Creek; but in some workings by the old scheelite mine at South Heathcote the silurian rocks were exposed close to the diabases; there is no apparent sign of contact alteration in the silurians; the development of the scheelite was probably a secondary change due to the action of solutions.

III. (B).—*The Ordovician.*

The ordovician rocks to the south and west of Heathcote are in the main sandstones, quartzites, shales, micaceous mudstones and shales. The strike is generally from north to south; but near Heathcote it changes to from N. 30 W. to S. 30 E. The beds, as a rule, are not much contorted, and the bedding is fairly regular. Some of the beds which had been mapped as ordovician slates, Mr. Howitt has determined as phyllitic schists. Most of the ordovician rocks still clearly show their clastic origin, and they have not been converted into schists. The rocks are themselves unfossiliferous, except for a band which lies along the eastern border of the ordovician series, in the parish of Knowsley East. The fossiliferous band occurs across the paddocks from 3q, 3p, 3m, 3j, 3n, 3l, and 3i. It has been carefully described by Mr. Lidgey and Mr. Ferguson, and the latter has twice collected from it a series of fossils. The first determined fossil from this band was described by Mr. R. Etheridge, jun., as a new genus of trilobite, of cambrian age. He named it Dinesus ida.

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1 The reference numbers are to the bibliography on p. 151.

III. (C).—*The fossils of the Dinesus ida Beds, and Notasaphus, a new genus of Trilobites.*

The need for more precise determination of the age of the Dinesus ida beds renders necessary reconsideration of the fossils found in them. Some supposed graptolites are too indefinite to be of use. The trilobites give the most important evidence. They were discovered by Mr. Ferguson, and some specimens were collected by Mr. Lidgey. The specimens consist of some cranidia and pygidia scattered together in an iron-stained shale. Mr. R. Etheridge, jun., who described the specimens, naturally concluded that they belonged to the same species. Mr. Etheridge gave a detailed description of the material then available; he referred it to a new genus and species, Dinesus ida. He did not refer the genus to a family, though he carefully contrasted it with several lower cambrian genera.

In order to obtain more material to settle the generic affinities of Dinesus, Mr. Ferguson made an excavation in the shales during last June, and obtained additional specimens of the trilobites. The new specimens are also fragmentary, but their evidence shows that at least two distinct trilobites have been included in Dinesus ida. They show that the pygidia and cranidia figured as Dinesus do not belong to the same genus. The pygidia figured by Mr. Etheridge agree better with some cranidia recently obtained by Mr. Ferguson. One specimen of Dinesus shows two of the thoracic segments.

Mr. Ferguson's recent collection enables me to suggest the following arrangement of the trilobite remains from this horizon.

1. Family Asaphidae.

Genus *Dinesus*, R. Etheridge, fil., 1896.

Diagnosis.—An asaphid with a nearly smooth glabellum, which has the sides sub-parallel or slightly contracted in front; the axial grooves are deep. The third side-lobes are cut off from the rest of the glabellum by the junction of the third side furrows and the neck furrow. Eye lobes small, and slightly projecting. Facial suture cutting the frontal border in front of the axial

groove. The fixed cheeks are triangular, long, regularly tapering to the front; they are gently convex. Neck furrow deep and straight. Thoracic segments large; the number is probably small. The pleura are wide, but short.

Type species, *Dinesus ida.* R. Eth. fil.: Cambrian Fauna in Victoria. Proc. R. Soc. Vict., Vol. VIII. (new ser.), 1896., pp. 56-57, pl. 1, fig. 1, 2, 3 and 4, not fig. 5 and 6.

This genus differs from *Asaphus* by its large, parallel-sided glabellum, small eyes, triangular fixed cheek, and much deeper thoracic segments.

Genus *Notasaphus*, n. g.[1]

Diagnosis.—An Asaphid, with glabellum expanded widely in front; it is crossed by deep, well marked neck furrow, with a slight projection on the middle line. Lateral furrows barely recognisable. Fixed cheeks broad behind, and with a well-rounded expansion in front of the deep, well marked eye lobes. Free cheeks large.

Pygidia large, with three or four large annulations on the axis. In the front pygidial segments the pleura are wide; but the hindermost pleura are narrow, and the whole bordered by a wide doublure with the edge broken into four, five or six pairs of long, projecting spines. Number of thoracic segments unknown.

Distribution.—Lower ordovician. Victoria.

Type species, Notasaphus fergusoni, n. sp. (Pl. XXVI.)

Affinities.—The collection may include two species of this genus as the number of spines and width of the doublure on the pygidia vary. The cranidia found all appear to belong to the same species, and one of them was attached to a pygidium with five pairs of spines. This genus appears to be an asaphid, as the cephalic shield and pygidium are large and sub-equal, and it no doubt had but a small number of thoracic segments. Only some isolated fragments of the thoracic segments remain.

The genus differs from the other genera of Asaphidae by its spiny pygidium; but as a doublure is found in some asaphids

[1] From Greek, νοτιος—southern.

the development of spines is not remarkable. The genus resembles Asaphiscus, Meek, 1873, which has, however, a conical glabellum. The spiny border of the pygidium resembles that of Ceraurus (syn. Chicrurus), but Notasaphus appears to be a true Opisthoparian (using Beecher's classification), as the specimens suggest that the genal spines were born on the free cheeks.

Dinesus and Notasaphus both have the characters of ordovician rather than of cambrian trilobites. They might be upper cambrian; but their evidence does not necessitate the separation of the Dinesus ida beds from the ordovician system.

In some shales associated with the trilobite bed are some fossils resembling graptolites or algae. Mr. T. S. Hall has failed to find any more definite evidence than hydrotheca of the Bryograptus type, so they give us no definite evidence. In Mr. Ferguson's later collection there are a few brachiopods, which have been examined by Mr. F. Chapman, who has reported on them, and regards them as of ordovician and probably even of upper ordovician age. The strike of the fossiliferous band is conformable with the strike of the overlying ordovician beds. It seems to me safest, with our present knowledge, to include them in the ordovician, as the lowest part of that system along the Heathcote line. The beds may be shown on the Victorian Survey Map as simply Dinesus beds of lower ordovician age.

III. (D).—*The Heathcotian Series.*

The last rocks of this area may be grouped together as the Heathcote series. They may be divided into two main divisions: the first includes some clearly altered sediments; the second a series of altered igneous rocks.

The microscopic structure of the rocks has been carefully described in Mr. Howitt's excellent memoir, to which reference may be made for detailed description of most of the rocks and the character of their minerals. Mr. Howitt has determined the rocks of the acid series as aplites, granophyres and labradorite-porphyrites; and the rocks of the basic series he has identified as diabase, diabase-porphyrite, enstatite-diabase-porphyrite and hornblende-diorite; and one very altered series is referred to as spilite.

IV.—The Petrography of the Heathcote Rocks.

With Mr. Howitt's description of the petrography of the rocks I am in agreement, except in a few minor matters of nomenclature. The rocks may be divided into four groups—the unaltered sediments, metamorphic rocks, acid igneous rocks, and basic igneous rocks.

The unaltered sediments show nothing of special interest. Reference has already been made to the occurrence of fragments of the diabasic materials in the silurians. The ordovician rocks are normal clastic rocks, considerably crushed, but not foliated.

The metamorphic rocks of the Heathcote series are of two types. They include schists and sandstones. As a type of the altered schists I may refer to a specimen collected 130 yards west of the so-called copper mine, on the Murray road, two and a-half miles north of Heathcote. The rock is a phyllite, traversed by two distinct cleavage planes. The rock was first altered by the development of a foliation, which formed alternate bands of fine grained argillaceous matter and quartz. It was subsequently cleaved obliquely to the foliation planes. The rock breaks readily along the second planes, and these are clearly shown in section as they are marked by limonite stains. The typical rock of this group is phyllitic schist.

The second type of the metamorphic rocks includes a series of black cherts, which are especially well shown near Lady's Pass in Dargile. These cherts when fresh are of a black colour with a satiny lustre. When exposed for some time to the weather, they become grey or they may be quite bleached. These rocks have been described by Mr. Howitt as adinoles. An adinole is a rock altered by a basic intrusion, and the term seems to imply the absorption by the altered rock of some material from the intrusive rock. Two analyses of adinoles given by Rosenbusch[1] show 8.33 and 7.77 per cent. of soda respectively, whereas the analysis of the Heathcote rocks, made by Mr. F. Stone for Mr. Howitt,[2] show only 0.84 and 1.98 per cent. of alkalies. The analyses are as follows :—

1 Rosenbusch: Elemente der Gesteinslehre, 1898, p. 333.
2 Howitt, *op. cit.*, p. 8.

I.		II.		III.		IV.
SiO_2 - -	91.08	SiO_2 -	92.74	SiO_2 -	72.63	76.30
Al_2O_3 - -	6.00			Al_2O_3 -	15.81	14.68
Fe_2O_3 - -	tr.			FeO -	0.74	trace.
CaO - -	0.14			CaO -	1.02	0.18
MgO - -	.25			MgO -	1.21	0.02
K_2O - -	1.82	K_2O)	.84	K_2O -	0.75	0.53
Na_2O - -	.16	Na_2O)		Na_2O -	8.33	7.77
Loss on ignition	.96 [1]			H_2O -	0.61	0.48
	100.41				101.10	99.96
				Sp.G.	2.778	2.637

I. "Metamorphosed Sediment," analagous to adinole, allotment 12, Parish Crosbie. Howitt, A. W., "Notes on Diabase and Adjacent Formations of the Heathcote District," p. 8.

II. The same, No. 18 Gatehouse, at Heathcote. Howitt, A. W. *Op. cit.*, p. 8.

III. Adinole, Heinrichsburg, near Mägdesprung. Harz. H. Rosenbusch, "Elemente der Gesteinslehre," p. 333.

IV. Adinole, Gitzhügel, near Hasselfelde. Harz. H. Rosenbusch, *Op. cit.*, p. 333.

The acid igneous rocks have been carefully described by Mr. Howitt, who states that "I have felt much difficulty in assigning a place in classification to these granitic rocks." (6, p. 5.) He finally called them aplites and suggested for them the provisional term of plagioclase-aplites. With Mr. Howitt's determination of the mineral constituents and structure of these rocks I entirely agree. There are two distinct varieties of rock. The first—those identified as aplites—consists of orthoclase in eroded and altered crystals, idiomorphic crystals of plagioclase, rounded grains of quartz, and flakes of colourless mica. The plagioclase, as Mr. Howitt remarks, is "more or less completely replaced by flakes and rosettes of a colourless mica." Biotite is also present in small patches.

In the second variety of rock—Mr. Howitt's labradorite-porphyrite—the structure is porphyritic, and the base is granophyric. The colour of the rock is dark grey to bluish or blackish grey. Plagioclase occurs both in phenocrysts and in radial tufts.

[1] This sample lost .20 per cent. on drying at 212 deg. F.

The plagioclase, according to Mr. Howitt's measurements, is a member of the labradorite group. There is also an amphibole, either anthophyllite or a monoclinic species with a nearly straight extinction. The rocks of this second type Mr Howitt described as later effusions from the aplite magma, and he calls them labradorite-pophyrite.

The two varieties of the rocks are probably associated, as Mr. Howitt concluded, and the labradorite-porphyrite is intermediate between the more acid variety and the diabase.

The use of the term aplite for either of the rocks seems to me open to doubt. Taking Rosenbusch's[1] last definition of the term aplite, he describes it as "a panidiomorphic granular rock, which consists of predominant potash felspar (orthoclase, microcline with lattice structure, microperthite, more rarely microclinmicroperthite), and quartz with acid plagioclase and a very limited quantity of muscovite and biotite, or both these micas." The structure, therefore, of an aplite is panidiomorphic, whereas in these Heathcote rocks the structure is hypidiomorphic. The rock, moreover, occurs more in masses than dykes, and it seems to me safer to regard the rocks as fine-grained granodiorites. It is quite natural to find them associated with later effusions, as Mr. Howitt describes them, or possibly dykes having the chemical character of rocks of the intermediate group. The porphyritic granophyric labradorite rock in allotment No. 16, at South Heathcote, can be more easily explained as derived from a granophyr than from an aplite.

The typical granodiorites occur at the Red Hill, where they are seen to be clearly intrusive into the diabase series. They also occur in the area round the water reserve, where they occur as a series of small tors.

The labradorite-porphyrite is best shown in South Heathcote, on the northern side of Photograph Knob.

The Diabase Series.

The rocks of this series, as Mr. Howitt has pointed out, are very varied in their petrographic characters. Many of them, such as the diorite, the enstatite-diabase, and most of the

[1] H. Rosenbusch: Elemente der Gesteinslehre, 1898, p. 206.

porphyrites, have the characters of intrusive rocks. In various parts of the series there are diabases which have the structures of lavas, though the material is now entirely altered. Photograph Knob, South Heathcote, consists of one of the most interesting rocks in this series; it has the characters of a volcanic agglomerate. Hence, especially at South Heathcote, some of the diabases are of eruptive and volcanic character.

V.—Age of the Heathcotian Series.

According to the view which has hitherto prevailed, the Heathcote series is of post-silurian age. In that case the rocks of the diabase series are intrusive into the silurians.

(A).—*Relation with the Silurian.*

The first evidence against this view is the complete absence of any contact alteration along the line of junction of the diabase and silurian series. Where they are in close juxtaposition the silurian rocks have not been baked. Lidgey has already quoted the occurrence of pebbles of the metamorphic rocks in the silurian; and the microscopic examination of the basal silurian rocks at the Copper Mine shows that they contain a considerable proportion of diabasic material. These facts clearly show that the silurian is later than the Heathcotian series, and is resting unconformably upon it.

(B).—*Relations with the Ordovician.*

The relation of the ordovician and eruptive rocks is less clear. As a rule the junction is somewhat obscure; and I have not attempted to follow it all along the line. I have examined typical sections where the ordovician and the diabase series occur in contact, and in some cases found no evidence of contact alteration. In places, as at Red Hill, the diabase series is separated from the ordovician rocks by a band of schists, and I have not been able to find any sharp junction between these schists and the overlying ordovician beds; but, on the other hand, I have not been able to see any passage from the schists into the ordovician beds. I have in no case been in

doubt, after the application of the microscope, as to whether a rock belonged to the schistose or to the ordovician series.

In Craven's paddock, in Knowsley parish, allotment 32, the two rocks can be well seen in contact close along the eastern fence. Here, as elsewhere, the junction between the hard cherts of the metamorphic series and the normal slates and sandstones of the ordovician series can be clearly recognised.

A serious difficulty in the view that the diabase rocks were intrusive into the ordovician rocks is the sporadic character of contact alteration along the line of junction. Thus in Mr. O. A. L. Whitelaw's sketch map of Heathcote, the diabases are represented in contact with the ordovician rocks from the northern boundary of the parish across Mount Ida Creek and McIvor Creek to the west of the northern end of the township. Along this line of two and a half miles no metamorphic rocks are represented as occurring between the ordovician and diabase series. In the Heathcote township there are two blocks of metamorphic rocks. One is shown on the map to the north and east of the water reserve; but these metamorphic rocks, instead of occurring between the diabase rocks and the ordovician, are on the wrong side of the igneous series. A small narrow band of metamorphic rocks occurs at Red Hill; it is a quarter of a mile in length, about ninety yards in width at the thickest point; it thins out to north and south, leaving unaltered ordovician rocks resting directly upon the diabases. Then follows another mile and a half without any metamorphic rocks along the contact; then, close by a small patch of diorite on the eastern side of the road going to Arygle's reef, there is another patch of metamorphic rock (Pl. XXIV., Fig. 1). It forms a bay running into the diabase series, which occurs round it on the north and east; on the south is a small outcrop of diorite, which appears to be sharply marked off from the ordovician rocks by a line running from north-west to south-east. This line cuts with equal abruptness straight across the metamorphic rocks, the diorite and the diabase, as if they were all part of the same series. The last patch of the metamorphic rocks occurs in South Heathcote, in allotments Nos. 15 and 16 (Pl. XXIV., Fig. 2). Here a bay, represented on the map as unaltered ordovician, runs up

between the diabase on the north and an intrusion of aplite on the south-east. The unaltered ordovician is shown as half a furlong in width, but the only part which is represented as metamorphic is a circular patch at the extreme head of this ordovician bay. Had the metamorphic rocks been formed by the alteration of the ordovicians owing to the intrusion of the diabases and the aplites, then we should have certainly expected the whole of this narrow band of the ordovicians to have been altered.

The map at the northern end of the Heathcote series is equally difficult to explain on the view that the metamorphic rocks have been formed by the alteration of the ordovicians (Pl. XXIV., Figs. 3, 4). For instance, the plan of Crosbie and Redcastle (Nos. A and B, opposite p. 4, in Mr. Howitt's Monograph) shows one thin band of metamorphic rock in the southern half of paddock 4C; it lies between diabase on the east and the ordovician on the west; but the ordovician rocks at the northern end overlap the metamorphic and rest directly on the diabases. Similarly on the western flanks of the diabase range at the south-eastern corner in Crosbie and south-western corner of Redcastle and north-western corner of Dargile. Here for most of the way the ordovicians are separated from the diabase by a band of metamorphic rocks; but at the northern half of paddock 15aa in Redcastle, the ordovician rocks are shown[1] to overlap the metamorphic band and rest directly on the diabases.

I have not been able to confirm the mapping in these localities, and have not visited the sections at the northern part of Crosbie. But the evidence is of importance as it is inconsistent with the view expressed in the memoir accompanying those maps. The field relations show, according to the work of the surveyor, that the ordovician rocks have been deposited unconformably on the edge of an old series of metamorphic rocks and diabases. In some cases the ordovicians were laid down upon the metamorphic rocks and in other cases directly upon the diabase. Moreover, the metamorphic rocks occur in places where there are no igneous rocks exposed in the immediate vicinity. Thus an exposure of

[1] Howitt, *op. cit.*, Map facing p. 4; the part in question is reproduced on pl. xxiv., fig. 4.

the typical cherts of the metamorphic series occurs along the eastern edge of allotment 30 in Knowsley East. The cherts occur between the silurian rocks on one side and unaltered ordovician on the west. There are some diabases a little south of this allotment, but none occur in it. If we explain the metamorphism there as due to a continuation of the diabases at a slight depth below the surface, then it is difficult to understand why there is no sign of alteration in the Dinesus ida beds, which must be approximately the same distance from any such assumed igneous mass.

Further evidence of a negative, but still of an important character is the fact that, although these diabases and igneous rocks occur along a line of nearly thirty miles in length, not one case is known of an apophysis or of a dyke striking from this series into the silurian or ordovician beds. Had this complex series of intrusive igneous rocks been injected in post silurian times, it is highly improbable that they should have kept along the actual line between the two lower palaeozoic systems, and should not, in a single case, have sent off an intrusion into the lower palaeozoic beds.

C.—*Geological Sequence at Heathcote.*

The evidence therefore seems to me conclusive that the series is as follows :—

Silurian - -	Sandstone and Quartzites.
	Unconformity.
Ordovician	Sandstones and slates. Dinesus ida beds.
Heathcotian	Granodiorites and granophyric porphyrites. Diabase series partly eruptive and partly intrusive. Cherts and schists.

According to this view, Mr. Dunn was right in regarding the rocks in the Heathcote series as pre-ordovician (or as he has put it, pre-silurian), and the diabases as in part effusive. Mr. Howitt was right in his rock determinations, and in the view that the diabase and acid rocks are mainly intrusive ; but both

the igneous and the metamorphic rocks were of pre-ordovician instead of post-silurian age.

VI.—The Distribution of the Heathcote Series in Victoria.

We must enquire where else in Victoria representatives of the Heathcote series occur. South of the Colbinabbin Range of the Heathcote Valley we find a similar rock series forming the Mount William Range, and extending from Mount William to south of the Lancefield Gap. The distribution of the rocks is well shown in the quarter sheet of the Geological Survey Map (No. 5, S.E.), where they are marked as "Trap or Hypogene and metamorphic silurian." The famous aboriginal quarries of Mount William were worked in outcrops of the amphibolites and impure nephrites of the Heathcotian series.

Mr. W. H. Ferguson[1] has shown that at Dookie there is another outcrop of diabases, and some specimens that he collected (now in the Mines Deparment) show that both the igneous and the associated metamorphic rocks have the characters typical of the Heathcotian series.

The bores put down by the Mines Department at Rushworth have revealed beneath the silurian sandstones and shales a thick series of hard black quartzites. I have had sections prepared from these rocks and they show that these deeper Rushworth quartzites have the characters of the Heathcotian cherts. Mr. A. M. Howitt has re-examined the bore records of the Rushworth bores and has sorted out the sample of the cores. The non-success of the boring for gold at that locality was due to the fact that the deeper bores passed into the barren series of Heathcotian cherts.

That the Heathcotian rocks had at one time a considerable extension further east than Dookie is probable from the evidence of the glacial conglomerates between Chiltern and the Springs. I have been guided over these deposits by Messrs. S. Hunter and A. W. Gahan. The most abundant foreign boulders in these deposits are cherts of the Heathcotian series. They are

[1] W. H. Ferguson: Notes on the Rocks at Dookie. Prog. Rep. Geol. Surv. Vict., No. viii., pp. 59-60, 1894.

associated with fossiliferous quartzites, which resemble those of Mount Ida. Both materials were probably derived from the denudation of an eastern extension of the rocks exposed at Heathcote.

South of the Lancefield Gap another outcrop of hypogene trap is recorded on the survey maps. I have been able to examine the rocks of this outcrop owing to the kindness of the Rev. H. Hennell, of Lancefield, who has collected some specimens for me.

Mr. Hennell's collection includes several varities of diabases, and a specimen of banded chert, which nearly resembles that of the Heathcotian series. The lithological characters and stratigraphical position of these rocks both suggest that they are a southern continuation of the Mount William range.

Near Geelong there are some more outcrops of the Heathcotian series. The two largest are shown on the Geological Survey Map, No. 24, S.E., and are there coloured as Trap or Hypogene. They were determined by Selwyn as diabases. An unmapped exposure occurs flanking the granodiorites of the Dog Rocks in the Moorabool Valley. As I understand that Mr. E. G. Hogg is undertaking a study of these rocks, I have only examined them as far as is necessary for the course of this paper. In the Moorabool Valley, opposite the Dog Rocks, is an irregularly foliated amphibolite (No. 149); it is mainly composed of needles of green hornblende, associated with zoisite and some material, probably derived from altered grains of felspar. The rock was a basic igneous rock, intensely altered—in part, no doubt, owing to the intrusion of the adjacent granodiorites of the Dog Rocks.

A second amphibolite (No. 143) of somewhat the same character occurs at George's Hill in the Barwon Valley. It was collected by Messrs. D. J. Mahoney and G. Voss Smith. This rock is less foliated and the remains of the felspars are larger and more angular than in the amphibolites from the Dog Rocks. The rock has been altered and the ferromagnesian constituents now consist of abundant needles and plates of amphibole. This mineral has an extinction of 12 degrees, a prismatic angle of about 123 degrees, and its pleochroism ranges from blue or bluish green to pale green and yellowish green. It may therefore be identified as arfvedsonite.

A rock represented by specimens in the conglomerates at the Barwon Falls has been called gabbro. It gives us a better indication as to the original character of one of the rocks of this series. It (147) is an enstatite-diabase, not unlike some of the specimens from Heathcote.

A specimen from the Barwon Falls, Geelong (150), is normal epidiorite, with the plagioclase well developed and the uralitic hornblende abundant.

An analysis of one rock from the outcrop near Geelong has been given in Selwyn's "Descriptive Catalogue of the Rock Specimens and Minerals in the National Museum," 1868, pp. 17, 94. It is identified as a "Greenstone (diabase)." The analysis was interpreted to identify the plagioclase as labradorite, and the green mineral as probably chlorite. The exact locality of the rock is not stated.[1]

Greenstone (diabase), Geelong.

Silica	50.84
Alumina	12.92
Sesquioxide of Iron	0.52
Protoxide of Iron	6.99
Lime	14.35
Magnesia	10.97
Potash	1.83
Soda	traces.
Water	0.71

In south-western Victoria, near Mount Staveley, we have another development of the Heathcotian rocks. They extend in a band, coloured on Mr. Everett's Geological Survey Map of Victoria[2] as "Porphyrites, Diorites, and Trachytoid rocks, &c." This band extends north and south for some twelve miles. I have been able to examine this bed near Mount Staveley, between Wickliffe Road and Glen Thomson. This hill is mainly composed of hard cherts of the Heathcotian type; they are associated with diabases, also like those of the Heathcotian series. The ridge may be regarded as another exposure of the pre-ordovician rocks.

1 *Ibid.*, p. 94.
2 Geol. Survey, 1902.

The confused rocks at Waratah Bay, Cape Liptrap, may include an outcrop of the Heathcotian series. Mr. Stirling[1] has recorded the occurrence there of "hard felsitic beds" "either silurian or pre-silurian"; of a gabbro with serpentine veins; and of a "hornfels-like contact rock." But he regards the gabbro and diabasic rocks as associated with deep-seated apophyses, from the granitic area of Wilson's Promontory; and the granitic rocks there have been generally regarded as devonian in age.

On Mr. Stirling's plates some rocks in fig. 1 are marked as cambrian; in fig. 2 the diabase or "melaphyre" is shown as intrusive into the silurian (?); in the view of Waratah Bay the "felsitic jointed rock" is stated as pre-silurian (?); and in the sketch section at "Serpentine Dyke, to west of Bird Rock," it is said to be cambrian, and the serpentine is shown intrusive into it, separated by a "contact rock (mica porphyrite)."[2]

Another area where Heathcotian rocks may occur is on the line of junction of the silurian and devonian rocks in Wonnangatta. The most probable locality would be in the Howqua Valley, south of Mount Buller. Mr. Murray's[3] report on this district refers to the upper silurian beds being there "partly metamorphic in character." So far I know of no certain evidence of Heathcotian rocks in that area.

VII.—Relations of the Ordovician and Silurian Systems.

The above conclusions help us to understand the relations of the ordovician and silurian deposits in Victoria. It has been well known since the time of Selwyn's work that the ordovician and silurian rocks meet along a line running from Melbourne northward through Heathcote; but no very satisfactory junctions have been found along this line.

Starting at the Mount William Range the hills are formed by a continuation of the Heathcotian series. Immediately at the

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1 J. Stirling: Notes on the Silver Deposits and Limestone Beds of Waratah Bay. Prog. Rep. Geol. Surv. Vict., No. viii., pp. 68-69, pl. 4.

2 The general impression left by the above account is that the rocks are probably Heathcotian; but one of my colleagues on the Geological Survey is of opinion that the supposed pre-ordovician rocks are altered silurians.

3 R. A. F. Murray: Howqua Hills District. Prog. Rep. Geol. Surv. Vict., No. vii., 1884 (1885), p. 57.

western foot of the hills are the Lancefield beds; going westward we cross an ascending series of the ordovicians, coming first to the Bendigo and then to the Castlemaine divisions of this system. Whereas, on the generally accepted view that Victoria is in the main one great synclinal, we should expect to find the uppermost, and not the lowermost, of the ordovician beds nearest to the junction with the silurians.

So far there is no fully convincing, definite evidence of the silurian beds resting upon the ordovician beds. There are three possible cases. Specimens collected by Mr. Ferguson in Wombat Creek, in north-eastern Victoria, have enabled Mr. Robert Etheridge, jun., to record the occurrence of silurian fossils from beds above a series with ordovician fossils. But Mr. T. S. Hall's determination of the graptolites from that area suggests doubt as to the occurrence of both the ordovician and silurian systems of that locality.

A second possible case is at Costerfield. Ranft, in his "Origin of Gold," refers to the occurrence of abundant ordovician graptolites in the tip heaps in the mines of Costerfield, although the beds on the surface are there mapped by the Geological Survey as silurian. If Ranft and the Geological Survey are both right in their determinations, then the silurians at Costerfield rest upon the ordovicians.

The third possible case is at Sandy Creek, a tributary of the Mitchell River, in Dargo. Mr. Herman collected some fossils there, which have been identified by Mr. R. Etheridge, jun., as silurian, and the beds are marked accordingly on the last edition of the Geological Map of Victoria. Mr. Herman, however, had previously mapped these beds as middle devonians.[1] The collection included a *Productus*. Mr. Etheridge suggests that this fossil was accidentally included with the Sandy Creek fossils.[2] A definite conclusion in this case must await further evidence.

The Heathcote evidence gives a simple explanation of this remarkable fact that there is no evidence of the super position of the silurian on the ordovician. During the time of deposition of the ordovician rocks a high ridge probably extended across

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1 H. Herman: Trans. Austral. Instit. Min. Eng., vol. v., Paper No. 68.
2 R. Etheridge, jun.: Note forthcoming in Records Geol. Surv. Vict.

Central Victoria from south to north. The deposition of the ordovician beds began by the sinking of the ground to the west of the line from Heathcote to Melbourne, and by a second subsidence in eastern Victoria from Bogong to Dargo. The oldest deposits were naturally deposited on the sinking shore lines, so that the Lancefield series was laid down on the eastern side of the land made up of Heathcotian and perhaps also still older rocks; as the subsidences continued later sediments accumulated further and further to the west (Pl. XXV., Fig. 5). During the time represented by the unconformity between the ordovician and silurian rocks, the country to the west of the Heathcote-Melbourne line was probably upraised; subsidence or denudation in the counties of Evelyn, Anglesey and Rodney led to a silurian sea running northward from Port Phillip to the Murray basin. This silurian sea was bounded both to the west and east by highlands of ordovician rocks (Pl. XXIII). It is possible that gulfs from the ordovician sea ran into the old Heathcotian land area, Sandy Creek and Wombat Creek; and in these places the ordovician deposits may have been covered by silurian sediments. The silurian rocks may also have extended westward from Mount Ida over the eastern border of the ordovician series; but in all probability, the main part of the ordovician and silurian rocks were deposited in independent basins; and these basins were separated by a range of old rocks, which once extended from Geelong to Mount Camel, and of which the Colbinabbin and Mount William Ranges are the best preserved remnants.

The range of the Heathcotian rocks does not appear to have been continuous from Lancefield to Geelong even in upper ordovician times. No trace of it is known where the silurian and ordovician rocks occur near together, between Keilor and Sunbury. Rocks of the Melbournian division of the silurian system are exposed near rocks belonging to the upper ordovician. Thus, near Diggers' Rest, there are slates with Dicranograptus ramosus and Coenograptus gracilis, which are regarded as upper ordovician. The slates along the Coimaidai Creek, near Bacchus Marsh, contain Didymograptus caduceus, Didymograptus extensus and Tetragraptus quadribrachiatus; they are typical of the Castlemaine series, the uppermost of Mr.

Hall's three subdivisions of the lower ordovician. At Matlock we have again upper ordovician graptolites such as Dicellograptus morrisi, and Diplograptus foliaceus. It is therefore probable that while the ordovician series was being deposited, denudation was destroying the land area of Heathcotian rocks. The transgressions of the ordovician sea carried the higher part of the ordovician rocks round the southern flank of the Mount William and Lancefield Ranges across the line that formerly connected them to the Heathcotian rocks near Geelong. In the neighborhood of Melbourne the rocks of the silurian and ordovician systems are not, so far as I know, exposed in actual contact; for the junction is covered by the basalt sheets. Yet it is possible that the Melbournian rocks rest unconformably upon the upper ordovician.

Again, east of Melbourne, in the basin of the Upper Yarra, and on the main divide near Mount Matlock, there are some upper ordovician rocks; they show that the ordovician transgression had carried the sea into the area occupied by land throughout the lower ordovician.

VIII.—The Subdivision of the Silurian System.

The relation of the ordovician and silurian rocks in Victoria raises the question of the silurian succession in Victoria. Surprise has often been expressed at the absence of clear junctions between the rocks of those two systems or of the superposition of the silurian upon the ordovician. But, as we have seen, this difficulty is explained by the geology of Heathcote.

The silurian rocks of Victoria occur in three distinct types. There is a series of coarse grained shore deposits which are best shown at Mount Ida, near Heathcote. They consist of coarse-grained conglomerates, grits and sandstones. The second type consists of alternations of shale and sandstone. It is well developed around Melbourne, near which the beds are often intensely contorted. The third type consists of a series of lenticular masses of limestone, associated with sandstone and shales; they occur at Lillydale, Loyola, Cape Liptrap and the Thomson River. The relation of these three lithological divisions of the silurian is obscured by the intense folding of certain bands. These contortions are especially well shown near

Melbourne, in our most familiar silurian sections; hence there has naturally been a tendency to exaggerate the importance of this folding in the Victorian series. The foldings occur on certain lines of fracture and contortion, which are separated by broad bands, in which the silurian rocks have a fairly normal sequence. The silurian rocks seem to me to be bent into two main anticlinals and two main synclinals (Pl. XXV., Fig 6). Along the eastern side of Melbourne is an extremely contorted zone, which is especially well shown in the cutting by the Yarra at the Johnston Street Bridge and near Heidelberg. East of this Melbourne fracture zone the beds have a regular dip to the west. This slope is part of a great anticlinal, of which the axis passes through Warrandyte. Along this anticlinal axis there is another line of contortions and faults, along which occurs a series of auriferous quartz reefs. The eastern leg of the anticlinal is much steeper than the western; and beyond it we come to the great synclinal which passes through Lillydale and Yering. We will therefore call it the Lillydale synclinal. A smaller synclinal with some Yeringian beds appears to occur in the upper Yarra. Eastward again we come to another great anticlinal. Some ordovician beds are exposed in the axis of this anticlinal near Matlock; we may therefore call it the Matlock anticlinal. To the east again comes the great synclinal of Walhalla; its two legs are said by Mr. O. A. L. Whitelaw to have a very regular dip, though the beds along the axis line of this synclinal are intensely folded and contorted. Beyond the Walhalla synclinal the beds are unconformably covered by the rocks which are included in the devonian system.

In tracing the folding of the silurians it is important to get a palaeontological basis for the correlation of the beds; but unfortunately, owing to the comparative scarcity of fossils, their imperfect preservation, and the great difference in characters between the limestone and shale faunas, the palaeontological evidence is at present insufficient. There seems, however, to be evidence of two main subdivisions; the first we may call the Melbourne series or Melbournian; many fossils have been obtained from it at Moonee Ponds and at the Yarra improvements; and it can be traced north-westward from Melbourne through Keilor, East Kilmore and Heathcote. The beds at

Reefton, MacMahon's Creek, Macclesfield, Alexandra, and Matlock also seem to belong to the Melbournian horizon.

The second series we may call the Yeringian, after Yering north of Lillydale, where the beds have yielded a small brachiopod fauna. These beds are best shown at Lillydale, but the name Yeringian is preferable, as based on a native Australian place name. This Yeringian series includes the most important silurian limestones, including those of Lillydale, Loyola, the Thomson River, Cape Liptrap, and also the beds of Seville and various localities in the basin of the Woori Yallock. We should expect this horizon also to appear in the synclinal to the west of the Warrandyte anticlinal; but so far I know no definite palaeontological evidence of its occurrence here.

No satisfactory list of the distinctive fossils of these two horizons can yet be drawn up; but I may quote the following species, using the names generally known in Victoria, without any attempt to revise the nomenclature.

MELBOURNIAN—

Phacops (Odontochile) caudatus, Brgn.
Forbesia euryceps, McCoy.
Homolonotus harrisoni, McCoy.
Cyphaspis spryi, Greg.
Hapalocrinus victoriae, Bath.
Retiolites australis, McCoy.
Spirifera plicatella (L.), var. macropleura (Conr.).
Cardium gippslandicum, McCoy.
Orthoceras (Cycloc.) ibex, Sow.
Orthoceras bullatum, Sow.

YERINGIAN—

Phacops (Portlockia) fecundus, Barr.
Lichas australis, McCoy.
Homolonotus sp. n.
Leptaena (Leptagonia) rhomboidalis (Wilck). ?
Spirifera sulcata, His.
Spirifera reticularis, L.
Pentamerus australis, McCoy.
Orthoceras lineare, Mst.
Trochus (Scalactrochus) lindstromi, Eth.
Pleurotomaria (Phanerotrema) australis, Eth.

Bellerophon cresswelli, Eth.
Tremanotus pritchardi, Cresswell.
Favosites grandipora, McCoy.

IX.—Summary of Conclusions.

1. The heathcotian series of Victoria consists mainly of phyllites and schists, with diabases, porphyrites, and amphibolites. Some of the igneous rocks are intrusive, others are eruptive, and some are volcanic agglomerates.

2. The heathcotian series is of pre-ordovician age. The evidence at present is insufficient to show whether it be cambrian or pre-cambrian. It is probably, however, more recent than the metamorphic rocks of north-eastern Victoria and of Dundas.

3. The Dinesus ida beds may be regarded as of lower ordovician age, and they contain a new genus of trilobite, Notasaphus.

4. Dinesus, so far as the available evidence goes, may be included in the Asaphidae.

5. The heathcotian series is best exposed on the Colbinabbin and Mount William Ranges. The latter extends from Mount William to the south of Lancefield Gap, and has an outlier in Deep Creek, south-east of Lancefield. Representatives of this series also occur at Dookie; under the silurian rocks of Rushworth; some miles west and north-west of Geelong, in the valleys of the Barwon and the Moorabool; at Mount Staveley in Western Victoria. Probably also at Waratah Bay, Cape Liptrap. Possibly also on the Howqua River.

5. The heathcotian rocks formed, in lower ordovician times, an extensive land area across Central Victoria. By the upper ordovician times, the sea had spread eastward across what is now the Melbourne basin and the Upper Yarra.

6. The silurian system in Victoria may be divided into two divisions, a lower or Melbournian and an upper or Yeringian. The silurian system occurs partly in a series of gentle folds and partly in belts along a series of meridional fracture lines, along which the beds are intensely contorted. Going eastward from the western edge of the series the main folds in the silurian are (1) the contorted zone of the Melbournian

beds; (2) the Warrandyte anticlinal; (3) the Lillydale synclinal; (4) the anticlinal of the Upper Yarra, in the centre of which, near Matlock, upper ordovician rocks are exposed; (5) the geosynclinal of Walhalla.

7. The heathcotian rocks are the fragments of the old framework upon which Victoria has been built.

EXPLANATION OF PLATES XXIII.–XXVI.

Plate XXIII.

Sketch map of the distribution of land and sea in Victoria in ordovician times. The areas in black are the present outcrops of the Heathcotian series. In upper ordovician times there was a transgression of the sea round the northern end of the Colbinabbin Range and into the Upper Yarra.

Plate XXIV.

Fig. 1.—Map of part of Heathcote, showing diabase series in part between the metamorphic rocks of the ordovician, and also the overlap of the ordovician across the metamorphic series. From the Geological Survey Map of Mr. O. A. L. Whitelaw, as reduced in Howitt's Memoir.

Fig. 2.—Map of the relations of the ordovician and metamorphic rocks, near South Heathcote. After O. A. L. Whitelaw.

Fig. 3.—Copy of Mr. Lidgey's map of part of Crosbie, representing the overlap of the ordovician rocks across the metamorphics.

Fig. 4.—Copy of Mr. Lidgey's map of part of the parish of Knowsley.

Plate XXV.

Fig. 5.—Diagrammatic section showing the relations of the ordovician, heathcotian, and silurian rocks, near Lancefield.

Scale of Miles. 5 0 10 20 30 40 50